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Thermal gradient of local sheep and goats reared in the Brazilian semi-arid region

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ABSTRACT: In the Brazilian semi-arid region, small ruminants reared in the field, especially in the dry period of the year, may be subjected to thermal stress, which can compromise their homeothermy. This study aimed to evaluate the climatic indices, rectal temperature (R_T), surface temperature (S_T), thermal gradient between rectal and surface temperatures and the ambient temperature of Santa Inês sheep and Moxotó goats, reared in the Brazilian semi-arid region in two periods of the year (less hot and hot) and at three times (13, 14 and 15 h), using 24 animals, 12 of each breed, 6 males and 6 females of each species, grouped in a completely randomized design in a 2 × 2 × 2 factorial scheme (species, genders and periods), with 6 replicates. Ambient temperature and black globe temperature and humidity index in the periods and times were above ideal for the species, with low relative humidity. In both periods, the means of R_T remained within the normality standard for the species, but higher in sheep. S_T remained high for the two species and higher in sheep at the times evaluated. The thermal gradients were below ideal, indicating damage to the physiological capacity of the animals to maintain homeothermy in the environment in which they were.

Key words: adaptation; *Capra hircus*; heat stress; heat tolerance; *Ovis aries*

Gradiente térmico de ovinos e caprinos locais criados na região semiárida brasileira

RESUMO: Na região semiárida brasileira, os pequenos ruminantes criados a campo, especialmente no período seco do ano, podem ser submetidos a estresse térmico, o que pode comprometer sua homeotermia. O objetivo deste estudo foi avaliar os índices climáticos, a temperatura retal (TR), a temperatura superficial (TS), o gradiente térmico entre as temperaturas retal e superficial e a temperatura ambiente de ovinos Santa Inês e caprinos Moxotó, criados no semiárido brasileiro em dois períodos do ano (menos quente e quente) e em três horários (13, 14 e 15 h), utilizando 24 animais, 12 de cada raça, 6 machos e 6 fêmeas de cada espécie, agrupados em um delineamento inteiramente casualizado em esquema fatorial 2 × 2 × 2 (espécies, gêneros e períodos), com 6 repetições. A temperatura ambiente e o índice de temperatura de globo negro e umidade nos períodos e horários estavam acima do ideal para as espécies, com baixa umidade relativa. Em ambos os períodos, as médias de TR se mantiveram dentro do padrão de normalidade para as espécies, porém mais elevadas nas ovelhas. A TS permaneceu alta para as duas espécies e mais alta em ovinos nos horários avaliados. Os gradientes térmicos estavam abaixo do ideal, indicando prejuízo à capacidade fisiológica dos animais de manter a homeotermia no ambiente em que se encontravam.

Palavras-chave: adaptação; *Capra hircus*; estresse térmico; tolerância ao calor; *Ovis aries*

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Introduction

Arid and semi-arid regions are characterized by high temperatures, low relative humidity and water deficit, mainly in the dry period of the year and, these characteristics can compromise livestock productivity in these regions, particularly characterized by the farming of small ruminants, such as sheep and goats, due to their capacity for adaptation and production under extreme climate conditions, even in the prospects of climate change (Nunes et al., 2020; Façanha et al., 2020; Aboul Naga et al., 2021).

Rearing small ruminants is part of livestock production in northeastern Brazil, where the largest portions of sheep herds (66.7%) and goat herds (93.9%) are concentrated, with a total of 12.63 and 10.04 million head (IBGE, 2019), where animals are reared in extensive and semi-intensive systems, under direct solar radiation. Among the breeds reared in northeastern Brazil, the prominent ones are Santa Inês sheep, with dark coat, and Moxotó goats, which have white coat (Souza et al., 2019; Leite et al., 2021), animals that are adapted to the climatic conditions of the semi-arid region.

The impacts caused by heat can lead to an increase in physiological variables, and there may be an increase in rectal temperature, surface temperature, and respiratory and heart rates of the animals (Sejian et al., 2019; Furtado et al., 2020; Marcone et al., 2021; Al-Haidary et al., 2021), as ways of eliminating body heat, but the efficiency of these mechanisms depends on the thermal gradients between the body core and the skin and between the skin and the environment. Coat color can influence the magnitude of the absorbed and reflected radiation and, consequently, the amount of heat transfer between the surrounding environment and the animal's body, and the dark coat can absorb more heat from solar radiation than the light coat (Stuart-Fox et al., 2017; Al-Haidary et al., 2021).

In addition to coat color, the physiological variables of the animals are also influenced by the day periods, since ambient temperature is usually higher in the afternoon than in the morning, promoting an increase of these variables (Souza et al., 2012), regardless of the period of the year, and the situation worsens in warmer periods, when naturally the ambient temperature is already high in the afternoon. Internal factors such as hormonal differentiation of males and females also influence the increase of these variables (Silva et al., 2016).

For small ruminants, the ideal is that there is a thermal gradient around 6 °C between body core and skin surface temperatures and between skin surface temperature and ambient temperature (Medeiros et al., 2015), generating less energy expenditure to maintain the body core temperature within the normal limits, within which physiological and metabolic reactions can be performed without the occurrence of heating or cooling (Sejian et al., 2019).

Therefore, the objective of this study was to evaluate the thermal indices, rectal temperature, surface temperature and thermal gradients between rectal and surface temperatures and between surface temperature and ambient temperature of Santa Inês sheep and Moxotó goats, reared in the Brazilian semi-arid region in two periods of the year and at three times.

Materials and Methods

The procedures carried out in this study were approved by the Research Ethics Committee (CEP) of the Federal University of Campina Grande, Paraíba, Brazil, CEP Protocol No. 108.2017.

The present study was conducted in the sheep farming sector of the Research Center for the Semi-arid Region Development - NUPEÁRIDO, of the Center for Rural Health and Technology, at the Federal University of Campina Grande, Patos, Paraíba, Brazil (07° 05' 28" South, 37° 16' 48" West, 250 m of altitude), characterized by a BSh climate, according to Köppen's classification, with maximum average annual temperature of 32.9 °C and minimum of 20.8 °C and relative humidity of 61%.

Twenty-four animals, 12 Santa Inês sheep (black coat) and 12 Moxotó goats (white coat), 6 males (non-castrated) and 6 females (non-pregnant) of both species, with initial average live weight of 26 ± 5 kg and age of 12 ± 3 months, were used. The animals were kept in an extensive system and were evaluated during two distinct periods: less hot (July and August) and hot (September and October), where 8 data collections were performed during the four months. During the test and measurements of the physiological variables, the animals remained fasting and without access to water. They were grouped in a completely randomized design, in a 2 x 2 x 2 factorial scheme (2 species, 2 genders and 2 periods) with 6 replicates.

For the two periods studied, the environmental and physiological variables were measured during the afternoon, at three different times, characterizing three distinct thermal environmental conditions: 13 h – before stress (before the animals were exposed to the sun, they were in the shade for two hours), 14 h – stress (just after the animals were exposed to direct solar radiation for one hour), and 15 h – one hour after stress (in the shade).

The data of environmental variables, air temperature (A_T, °C), relative humidity (RH, %), were stored in a ONSET Comp® HOBO U12-012 datalogger, with one external channel and one internal channel coupled to a black globe positioned at a height similar to that of the animals, in the collection environments. The data were stored daily every hour throughout the experimental period. The black globe temperature and humidity index (BGTHI) was used to evaluate the level of thermal stress induced by the environment on the animals and was calculated using the equation reported by Buffington et al. (1981).

Surface temperature (S_T) was obtained through the arithmetic mean of the temperatures of the cervical, thoracic, and gluteal regions of the animal, measured with an infrared thermographic camera (Fluke Ti 25). Subsequently, the thermograms were analyzed with Smartview software version 4.1, which was used to obtain the average body surface temperature of the animals, considering emissivity of 0.98. Rectal temperature (RT) was recorded by introducing a digital veterinary thermometer into the animal's rectum (at a depth of approximately 2 cm) with the bulb adjacent to the rectal mucosa and holding it there until the reading stabilized. Thermal gradients were evaluated by the difference between rectal temperature and surface temperature (R_TS_T) and the difference between surface temperature and ambient temperature (S_TA_T).

The data obtained were subjected to analysis of variance (ANOVA) and the means were compared by Tukey test at 5% probability level, using the statistical program ASSISTAT (Silva & Azevedo, 2009).

Results and Discussion

The average air temperatures for the evaluated factors (environments, times, and periods) remained above the recommended thermal comfort zone for the species, with average relative humidity below the ideal (Table 1), A_T should be between 20 and 30 °C, with relative humidity between 50 and 70% (Eustáquio Filho et al., 2011; Lucena et al., 2013). A_T in the environment in the sun and in the hot period was higher, and the upper critical limit of heat tolerance in sheep and goats is $A_T \leq 36$ °C (Johnson, 1987), values found in the environment in the sun and in the hot period, which can compromise the performance and reproduction of the animals.

BGTHI levels for sheep and goats can be categorized as follows: values < 82: absence of thermal stress, >82 and <84: moderate thermal stress, > 84 and < 86: severe thermal stress and >86: extremely severe thermal stress (LPHSI, 1990), therefore, the climatic data obtained and BGTHI indicate that the animals were exposed to severe thermal stress.

Small ruminants kept in stressful environments, with high AT and low HR, increase their endogenous and surface heating, causing behavioral, metabolic, physiological, and reproductive dysfunctions, which compromise the maintenance of homeostasis (Darcan & Silanikove, 2018; Sejian et al., 2019), leading to increased physiological variables, which may favor reduced production and productive efficiency (Furtado et al., 2020; Marcone et al., 2021). In the study, A_T remained high even in a shaded environment, demonstrating that animals had difficulty dissipating heat sensitively, and the latent pathways of dissipation, respiratory rate and transpiration, were activated to dissipate excess body heat (Fonseca et al., 2019; Aboul Naga et al., 2021). In addition, unlike A_T, RH showed values considered low for thermal comfort for these animals. RH can favor heat exchange by evaporation, causing less stress on the animals (Façanha et al., 2020), however, very low values can dry the mucous membranes, hinder heat exchange through non-evaporative mechanisms (conduction, radiation, and convection) and evaporative mechanisms (sweat and respiration) (Sejian et al., 2019).

Rectal temperature is one of the critical physiological indices to identify thermotolerance in small ruminants. Regardless of sex and period, the R_T of the animals showed no significant difference ($p > 0.05$) before, during or after heat stress (Table 2). During stress, the RT values of sheep were higher ($p < 0.05$), suggesting a greater absorptance of the coat. These different temperature variations presuppose different interactions between radiation and the hair-covered surfaces (Mascarenhas et al., 2023).

The normal variation of R_T for the species ranges from 38.5 to 39.7 °C, reaching the minimum in the morning and the maximum in the afternoon (Shilja et al., 2016), and, even under stressful environmental conditions, these values remained within normal limits, demonstrating their adaptability to the climatic conditions of the Brazilian semi-arid region, resulting from the natural selection pressure to which they were subjected during their formations (Fonseca et al., 2019; Furtado et al., 2020) and the tolerance to the hot and dry climate of the Brazilian semi-arid region.

The surface temperature of sheep, regardless of the times, was higher ($p < 0.05$), with greater amplitude (2.76 °C) during thermal stress (Table 3), and this elevation is related to the

Table 1. Mean of environmental variables, ambient temperature, relative air humidity and BGTHI in the environments (shade and sun), at times (13, 14 and 15 h) and at times (less hot and hot).

Factors	Environmental variables		
	Air temperature (°C)	Relative humidity (%)	BGTHI
Environment			
Shade	34.63 B	30.06 A	83.55 B
Sun	36.61 A	26.67 B	84.97 A
Times			
13h	35.10 A	30.24 A	84.26 A
14h	35.65 A	28.28 B	84.20 A
15h	35.76 A	27.51 B	83.97 A
Periods of year			
Less hot	34.56 B	29.51 A	82.77 B
Hot	36.67 A	27.23 B	85.75 A
CV (%)	2.82	10.71	1.60

Means followed by the same uppercase letter between columns do not differ significantly from each other, at 5% probability by Tukey's test. BGTHI = black globe temperature and humidity index.

Table 2. Means of rectal temperature (R_T) for species (goats and sheep), for genders and for periods (less hot and hot).

Factors	Before stress (13h)	Stress (14h)	One hour after stress (15h)
Species			
Sheep	38.91 aA	39.80 aA	39.40 aA
Goats	38.87 aA	39.50 bA	39.29 aA
Genders			
Male	38.82 aA	39.55 aA	39.26 aA
Female	38.97 aA	39.75 aA	39.43 aA
Periods of year			
Less hot	38.83 aA	39.59 aA	39.32 aA
Hot	38.95 aA	39.71 aA	39.36 aA
CV (%)	0.61	0.67	0.55

Means followed by the same lowercase letter between columns and uppercase letters between lines do not differ significantly from each other, at 5% probability by Tukey's test.

Table 3. Means of surface temperature (S_T) for species (goats and sheep), for genders and for periods (less hot and hot).

Factors	Before stress (13h)	Stress (14h)	One hour after stress (15h)
Species			
Sheep	39.94 aA	42.76 aA	39.25 aA
Goats	38.83 bB	40.00 bB	38.51bA
Genders			
Male	39.48 aA	41.26 aA	38.96 aA
Female	39.29 aA	41.50 aA	38.80 aA
Periods of year			
Less hot	38.38 bB	40.13 aB	38.83 bB
Hot	40.40 bA	42.64 aA	38.93 cB
R^2	1.39	3.07	1.46

Means followed by the same lowercase letter between columns and uppercase letters between lines do not differ significantly from each other, at 5% probability by Tukey's test.

type of fur and color of the coat of Santa Inês sheep, which favor the absorption of sun rays. As for gender, although females tend to be more affected by hormonal factors, S_T was similar ($p > 0.05$) among the species under all conditions analyzed.

In the hot period, S_T (Table 3) was higher ($p < 0.05$), which can be justified by the higher A_T and the lower RH (Table 1). Among the times, there was a significant difference ($p < 0.05$) at 15 h, when the animals were exposed to the sun. The upper critical limit of heat tolerance in sheep is $A_T \leq 36$ °C (Johnson, 1987) and, although the animals respond well to direct exposure to the sun, exposure of sheep to A_T above this limit may induce thermo-physiological changes (Nunes et al., 2020; Furtado et al., 2020; Aboul Naga et al., 2021). Consequently, the A_T recorded during the present study indicated that the sheep were exposed to a stressful hot weather condition.

S_T is one of the most sensitive variables to determine the effects of the environment on the acclimatization of the animal (Pequeno et al., 2017), which may exceed the normal range under the influence of several factors (Shilja et al., 2016), such as A_T and coat color, which can influence the magnitude of the absorbed and reflected radiation and, consequently, the amount of heat transfer between the surrounding environment and the animal's body (Stuart-Fox et al., 2017; Al-Haidary et al., 2021).

The properties of adaptation to heat may depend on the morphological characteristics of the skin (color, thickness, sweat glands), as well as on the characteristics of the coat (fur thickness, length, diameter and density) that determine the ability of animals to dissipate heat through sensible and latent mechanisms (Amorim et al., 2019; Al-Haidary et al., 2021). The thermal effects of coat color depend more on long wavelength absorbance near infrared than on the short visible wavelengths of direct sunlight (Stuart-Fox et al., 2017).

T_S is a sensitive variable easily influenced by the increase in A_T, it is also affected by the time of day, as A_T increases, there is a reduction in the thermal gradient between the animal and the medium, and the animals trigger a series of thermal mechanisms, using them more intensely, also increasing the R_T.

The R_TS_T thermal gradient differed ($p < 0.05$) between species, genders, and periods (Table 4), and sheep had higher thermal gradients before and after stress. The means of R_TS_T were higher before (13 h) and after (15 h) stress for both species, a factor that hinders the heat dissipation process, since the existence of thermal gradient between the animal and the environment is fundamental for heat dissipation by sensible mechanisms.

Females had higher means of R_TS_T ($p < 0.05$) before and after stress and similar means ($p > 0.05$) during stress (Table 4), before and during stress, R_T was higher in females (Table 2), influencing the results of these gradients. Among the periods, there were significant differences ($p < 0.05$) and under stress conditions.

For domestic animals, the ideal is that there is a thermal gradient around 6 °C between body core and skin surface temperatures (Medeiros et al., 2015; Silva et al., 2019), so the body heat flow will be directed spontaneously to the extremities of the body, and metabolic reactions can be performed without heating the internal organs of the animal (Sejian et al., 2019; Souza et al., 2019).

The means of the R_TS_T gradient were below 2 °C for the species, genders, and periods, under all conditions evaluated, which can be considered low, hampering the exchange of heat from the body core to the skin of the animals and from their skin to the environment. Peripheral vasodilation increases blood flow to the body surface, increasing the surface temperature of the skin, facilitating the exchange of heat between the animal and the environment through sensible mechanisms (Pequeno et al., 2017; Torres et al., 2017; Ribeiro et al., 2018).

The thermal gradient R_TA_T at all times was higher ($p < 0.05$) in sheep (Table 5), which had the highest means of S_T, which may be due to the color of the coat of the species, as Santa Inês sheep, for having dark coat, absorbed more heat than Moxotó goats, whose coat is white.

The means of R_TA_T ($p < 0.05$) between females and males were similar ($p > 0.05$) under the three stress conditions

Table 4. Means of thermal gradient (R_TS_T) in the three stress conditions, for species (goats and sheep), for genders and for periods (less hot and hot).

Factors	Thermal environmental conditions		
	Before stress (13h)	Stress (14h)	One hour after stress (15h)
Species			
Sheep	2.11 aA	0.80 aB	1.74 aA
Goats	1.24 bA	0.94 bA	1.00 bA
Genders			
Male	1.13 bA	0.87 aA	0.99 bA
Female	2.22 aA	0.86 aA	1.75 aA
Periods of year			
Less hot	1.19 bB	1.12 aB	2.02 aA
Hot	2.16 aA	0.62 bB	0.71 bB
p-value	0. 36037	0.00019	0.01072

Means followed by the same lowercase letter between columns and uppercase letters between lines do not differ significantly from each other, at 5% probability by Tukey's test.

Table 5. Means of thermal gradient (R_TA_T) in the three stress conditions, for species (goats and sheep), for genders and for periods (less hot and hot).

Factors	Thermal environmental conditions		
	Before stress (13h)	Stress (14h)	One hour after stress (15h)
Species			
Sheep	5.79 aA	5.65 aA	5.42 aA
Goats	3.90 aA	4.06 aA	3.31 aA
Genders			
Male	4.98 aA	5.29 aA	4.54 aA
Female	4.71 aA	4.43 aA	4.19 aA
Periods of year			
Less hot	5.05 aA	4.86 aA	4.40 aA
Hot	4.64 aA	4.85 aA	4.33 aA
p-value	0.01412	0.06263	0.00005

Means followed by the same lowercase letter between columns and uppercase letters between lines do not differ significantly from each other, at 5% probability by Tukey's test.

evaluated, and between the periods, there was also no significant effect ($p > 0.05$) on this gradient (Table 5), which is relevant in the heat dissipation process, especially when it comes to non-evaporative mechanisms because, as A_T increases, this thermal gradient is reduced, increasing heat loss by evaporative mechanisms (Ribeiro et al., 2018; Sejian et al., 2019).

The means of the R_TA_T gradient for sheep were close to 6 °C under all evaluated conditions (Table 5), considered favorable for the exchange of heat from the body core to the skin of the animals, and from their skin to the environment. The increase in blood flow in the body surface facilitates the exchange of heat by the animal through sensible mechanisms (Pequeno et al., 2017; Torres et al., 2017; Amorim et al., 2019).

At high ambient temperatures, the body core temperature flows to the body surface and to the limbs of the animals, in the opposite situation, the skin temperature gradients extend along the limbs, and the central temperature is restricted to the trunk and head (Medeiros et al., 2015; Silva et al., 2019). Thermal conduction is important in the heat dissipation process, from the central core to the external surface of the animal, as well as from the surface to the surrounding environment (Fonseca et al., 2019; Aboul Naga et al., 2021).

Hot and dry environments can hamper the performance of animals because they result in low gradients, making it difficult to dissipate heat. Thus, it is possible to explain the increase in R_T and S_T and the low thermal gradient, since there is an accumulation of endogenous heat, requiring the activation of evaporative mechanisms of thermoregulation (Stuart-Fox et al., 2017; Silva et al., 2019; Leite et al., 2021).

Conclusions

The exposure of sheep and goats to thermal stress influenced the increase in surface temperature, especially of sheep, consequently influencing thermal gradients.

The recorded thermal gradients were below the ideal for the species, indicating damage to the physiological capacity of sheep and goats to maintain normal homeothermy in the environment in which they are.

The variation between the species in response to exposure to thermal stress can be attributed to the color of their coat.

Compliance with Ethical Standards

Author contributions: Conceptualization: NMHM, BBS; Data curation: NMHM, BBS; Investigation: NMHM, LFB, DAF, MRS; Methodology: NMHM, LFB, DAF, MRS; Project administration: NMHM, BBS; Resources: NMHM, LFB, DAF, MRS; Supervision: DAF, ANLC, BBS; Validation: DAF, ANLC, BBS; Visualization: NMHM, LFB, DAF, MRS; Writing - original draft: NMHM, LFB, MRS; Writing - review and editing: DAF, ANLC.

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